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Experimental Investigation of Electrostatic Charge Generation for Granules

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Abstract

In studies of granule electrification due to sliding, quantitatively evaluating the charging characteristic of single particles, rather than of a mass of granules as a group, is important for a fundamental understanding of the elementary tribocharging phenomenon, which is complicated, since it is resulted from electrical and physical properties of granules and operational environment conditions. In this work, charge transfer due to a single particle repeated sliding along metal plane for Polyvinyl Chloride(PVC)granules(diameter 1.1-4.1 mm, in the shape of half-circle or rectangle). The amount of transferred charge is expressed as a function of granular shape factor, such as length-ratio, sliding area, front-facing edge, as well as sliding velocity, plane angle and relative humidity. The transferred charge increases with length-ratio and area. Front-facing edge, plane angle, sliding velocity and relative humidity do have effect on the degree of electrification.

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Keywords: Granule; Electrostatics; Granular shape

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1. Introduction

When two particles approach each other in close contact, the transfer of electrons between atoms or molecules may occur, giving one particle a positive and the other a negative resultant charge. Such static electrification of particles involving contact and friction between particles is known as triboelectrification [1,2].The mechanism that generated the static charge was apparently quite complex. As Jesfis Guardiola[3] describled: briefly, when two bodies come into contact electrons transfer from one to the other forming an "electrical double layer" that consists of two layers of charge of opposite sign. These layers are located on or near each surface and the distance between them is only a few molecular diameters. If the bodies are suddenly pulled apart, the original electronic equilibrium cannot be re-established and one of the surfaces retains more electrons than before the contact was first established and the other will present a deficit. Obviously, the total charge of the two surfaces concerned remains constant, although if one of the surfaces loses the charge obtained (for instance, because it is a better conductor or is earthed) the global result of the phenomenon is to generate an electrical charge. The above is of course a very simple approach to the phenomenon of static electrification. A more complete description of the whole process can be found in [4-7]. In fluidization processes and granular flow systems, triboelectrification is inevitable due to the continuous and random motion of particles which results in numerous collisions, friction and rolling between particles and particles, particles and fluid, or particles and wall to occur constantly. The electrostatics on particles and walls may affect the hydrodynamics in the systems, and cause the formation of undesired byproducts. They can also result in inaccuracy in the measurement readings as well as malfunction of measurement instruments. In cases where the static charge is very high, hazardous discharge of the accumulated charge may cause sparks, fires or even an explosion, affecting process performance and endangering the safety of operators [8]. On the other hand, the proper usage of electrostatics can be beneficial in many industrial processes, such as printing, and dust removal. Therefore, it is of great significance to study the electrostatic phenomenon in fluidization and granular flow system to mitigate its negative effects and utilize its positive effects [9].

Granular material is commonly used in solid-handling or pneumatic conveying systems in the energy, chemical, pharmaceutical, and material processing industries. Various shapes of granules are commonly observed in these granular systems due to repeated mechanical attrition caused by interactions between granular material with system parts (such as feeder, valves, pipe wall and so on) [10]. During these processes, solid particles also have a natural tendency to acquire electrostatic charges through triboelectrification due to repeated collisions between particles with surfaces of a different material type. Electrostatic effects and the associated charge generation mechanisms are complex phenomena and often dependent on a variety of factors such as the physical, chemical and electrical characteristics of the material used and ambient conditions. This may give rise to poor reproducibility of experiments where such phenomena are the main focus of investigation. As a result, the number of work reported in the literature which involves measuring or calculating electrical charges on particles in granular flow systems has been limited due to the inherent difficulties in such investigation.

There have been many experimental studies conducted in this field to investigate the effects of various parameters on the electrostatic phenomenon. Most of the available papers are focused on the relationship between operating parameters and generated electrostatics. Guardiola et al.[11] investigated the influence of particle size, fluidization velocity, and relative humidity on fluidized bed electrostatics, and found that the degree of electrification was increased with increasing particle size and air velocity, while the influence of relative humidity was quite complex. Nomura et al. [12] studied in depth the humidity effect on the tribocharging of powder; they found that the absolute value of the saturated specific tribocharging of the powder decreased with increasing humidity, and the absorption hysteresis of the powder produced a large effect on the charging characteristic of powder. Saleh et al.[13] investigated the effect of several parameters, such as the chemical nature of the transport pipe, the particle mean size, the solids flow rate, the air velocity, and relative humidity, on the tribocharging of fine glass particles during pneumatic conveying. Greater electrostatic effects were observed for larger particles, high air velocities, high solids flow rate, and low relative humidity. Yao [14] carried out a comprehensive study of the granular size and shape effect on electrostatics in continuous recycled pneumatic conveying systems. Yao[15] also integrated various instruments including electrometers, electrical capacitance tomography (ECT) and particle image velocimetry (PIV) to characterize granular behavior and figure out the “electrostatic equilibrium state” for a pneumatic conveying system.

In studies of powder electrification due to impact/contact, observing the behavior of single particles, rather than of a mass of powder as a group of particles, is important for a fundamental understanding of the elementary process. The so-called “impact charging experiments” were carried out for the concept, in which polymer particles, mainly 3mm in diameter, as model particles were impacted on a metal target one by one, and the impact charges generated by single collisions were measured. Such experiments have been carried out by Masui and Murata [16,17], Yamamoto and Scarlett[18] and Matsuyama and Yamamoto [19,20] . Also, recently, Matsusaka et al. [21] performed single-particle experiments with a larger particle 30mm in diameter.

The aim of this work is to carry out an experimental study on the effect of granule shape and operating conditions on the electrostatic charging ability of polymer granules. An efficient and novel method is applied. In this paper, the impact charge is described as a function of the contact surface and operational conditions.

2 Experimental design

2.1 Experiment apparatus

This experiment apparatus is the same as Yao et. al[14]. A stainless steel plate (thickness 2mm, length 188mm) was placed in an inclined position from a stand to allow the sample particle to slide smoothly under the action of gravity and fall into the Faraday cage (TR8031, Advantest Corporation, Japan) below. The Faraday cage was connected to an electrometer (Advantest R8252 Digital Electrometer, Advantest Corporation, Japan) that was connected to a computer. The charge on the single particle was detected by the electrometer and the data were automatically stored in a computer at intervals of 0.5 s. During each test, the plate, Faraday cage and electrometer were grounded.

2.2 Particle properties

Polyvinyl chloride (PVC) particles are used in this experiment. The geometry of the granules can be classified conveniently by two basic shapes as defined in Fig.1: half-cylinder and cube. Compositional faces of each basic column are shown in Fig.1. For half-cylinder, half-circle was chosen for sliding surface. For cube, largest rectangle was chosen. Single particle size was characterised by the following natural length scales: length (L) and width (W) , also shown in Fig.1.

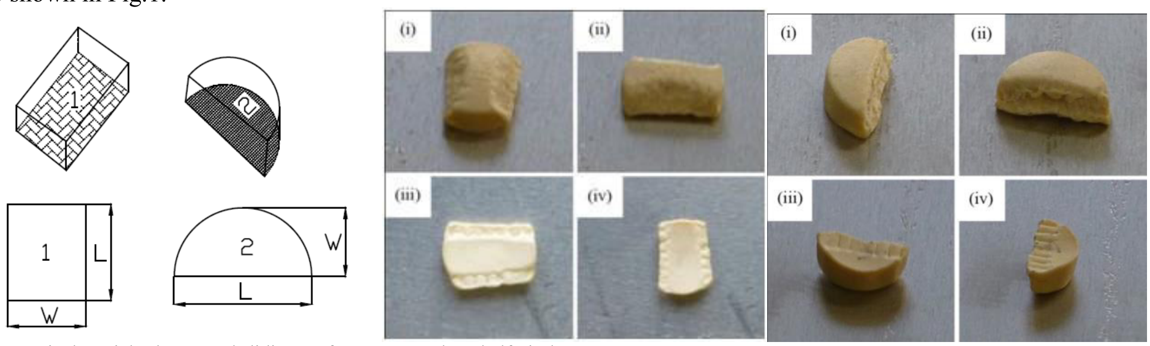


Fig.1. Typical particle shapes and sliding surface:1.rectangle, 2.half-circle.

The mass of single particle was measured using an electronic balance to an accuracy of 10^{-4} g and the mass-to-charge variation of the particle was then calculated. The length and width of the sliding face were measured using a micrometer to an accuracy of 10^{-4}m and the sliding area was then calculated. In this work, the length of the rectangle particles ranged from 2-6mm and the area ranged from 4-16mm^2. For the half-circle particles, the length ranged from 3-5mm and the area ranged from 4-16mm^2.

3 Results and discussion

3.1 Definitions

By comparing the length-to-width ratios, it is proposed that triboelectrification(charge generation) occurs anisotropically and preferentially along the directions defined by the length and width of the particles. A parameter termed length-ratio is thus defined to characterise the temporal variation:

Length-ratio (L_r)= length (L)/width (W), L>W. (1)

In this work, several factors effect on electrostatic charge generation, such as front-facing edge, length-ratio, area, relative humidity, plate angle and others, were investigated. To evaluate the effect due to a single factor, it is proposed to define the following functions:

Specific charge(q_m)=charge/mass(C/g) (2)

Specific charge density(q_d) = specific charge / area(C/g·mm^2) (3)

Specific charge to length-ratio(q_l) =specific charge / length-ratio (C/g) (4)

Specific charge density to length-ratio(q_r) = specific charge density/ length-ratio(C/g·mm^2 (5)

3.2 Influence of length-ratio

Yao et al. [14] had proposed that charge generation would be linked directly to the size and shape of particles. Length-ratio is the important characterization factor of particle size and shape. Here we study the effect of length-ratio by large amounts of particles with different length-ratio. Fig.2(a) illustrates the relationship between specific charge density and length-ratio after sliding. The experiments were conducted using PVC granules with half-circle face and rectangle face respectively and each granules slid at an 54°inclined plate by short edge(RH=50%).. For the sliding (Fig.2(a)) it is seen that for both half-circle particles and rectangle particles the specific charge density follow a linear relationship with length-ratio, which indicated that electrostatic charge follow a linear relationship with length-ratio. This agreed well with the previous work [14] which concluded that granules with larger length-ratio had tendencies to generate more electrostatics. In particular, with the same length-ratio, the half-circle particle tends to acquire higher electrostatic charge than rectangle particle. The least-square fitted linear function of specific charge density to length-ratio is given as

$$q_d = AL_r + B \tag{6}$$

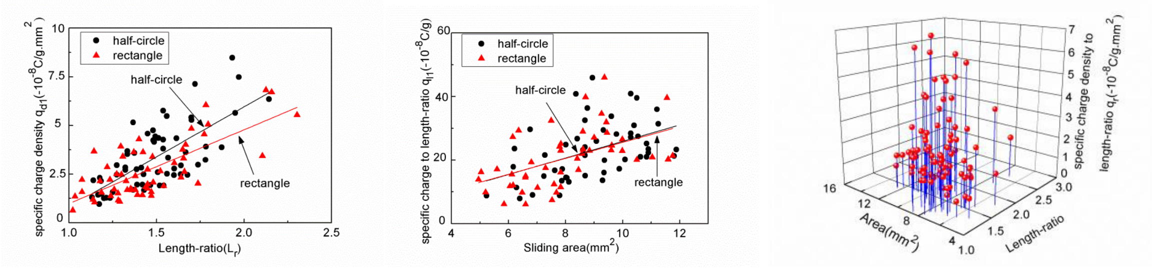
Table 1 A and B values for half-circle granules and rectangle granules

Half-circle granules		Rectangle granules	
A	B	A	B
5.13	-4.3	3.79	-2.81

It shows that particles with sharp angle tend to give rise to a higher electrostatic charge. This result is in agreement with several bibliographical works carried out on the behavior of single particles during their impact or transport. For example, Yao and Wang [14] who carried out triboelectric tests based on pneumatic transport of PVC particles, reported that the angular particles allow a stronger charge transfer. In addition, this result was supported by experimental work on horizontal pneumatic flow done by Saleh [13], who found that the highest charge was reached with particles of irregular shape.

3.3 Influence of sliding area

Fig.2(b) illustrates the relationship between specific charge to length-ratio and area after sliding. The particles slid in half-circle face shape and rectangle face shape. It is seen that for both half-circle particles and rectangle particles the specific charge to length-ratio increase with sliding area, which indicated that electrostatic charge increases with granular sliding area. With the same area, half-circle granular and rectangle granular tend to acquire the same electrostatic charge. This result agreed with the experimental findings by Cheng et al. [9], who the electrostatics generation in the downer reactor and observed that the averages induced currents increased with particle diameter. In addition, this trend was also supported by experimental work on tribocharging of aerosols of fine phosphate rock concentrations done by Marra et al.[22], who found that the generated charge of particles increased accordingly with the mean particle size, implying a greater extent of electrostatics. Masuda et al. [23] used Hert's theory to show that contact area during elastic collisions varied positively with particle size. All these findings indicated that the degree of electrification increased with contact area.



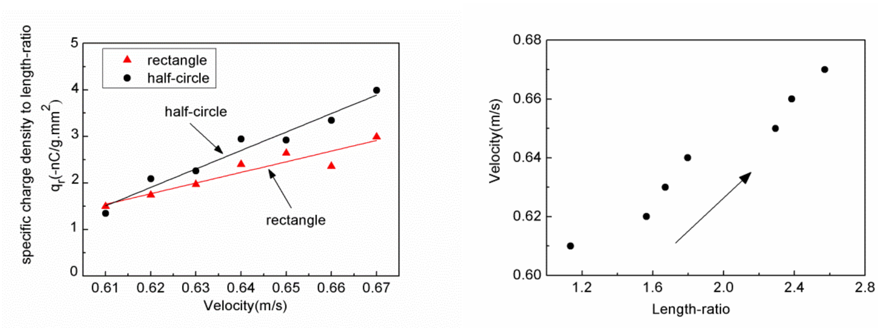
(a) (b) (c)

Fig.2. Specific charge to length-ratio as a function of: (a) the length ratio; (b) sliding area; (c) area and Length-ratio effect on charge generation

Fig.2(c) shows area and length-ratio both effect on charge generation. Electrostatic charge increases with area, which is independent of length-ratio. On the other hand, granular electrostatic charge increases with length-ratio, which is independent of area. However when the granular with small length-ratio and big sliding area, the electrostatic charge it acquired is lower than that with medium length-ratio and medium sliding area. It is obvious that the granular with big length-ratio and big sliding area acquires the highest electrostatic charge.

3.4 Influence of sliding velocity

Fig.3 illustrates sliding velocity effect on charge generation. Fig.3(a) shows for both half-circle particles and rectangle particles the specific charge density to length-ratio increase with sliding velocity, which indicated that electrostatic charge increases with granular sliding velocity. The previous under the same area, half-circle granular tends to acquire the higher electrostatic charge, which is consistent with the finding that with the same length-ratio, the half-circle particle tends to acquire higher specific charge density. Fig.3(b) shows the relationship between sliding velocity and length-ratio. The sliding velocity increases with granular length-ratio, which indicates that the long and narrow granular slides faster. This statement is consistent with the finding that electrostatic charge increases with the granular length-ratio and particles with sharp angle tends to give rise to a higher electrostatic charge.



(a) (b)

Fig.3. Sliding velocity effect on charge generation (a) velocity; (b) length-ratio

3.5 Influence of front-facing edge

When sliding along the pipe wall, the long edge and short edge of the rectangle-shape granular are front-facing edge respectively as well as half-cycle-shape granular. With different front-facing edge, the particles carry different electrostatic charge. The relationship is shown in Fig.4. It is clear that the electrostatics (specific charge density) of the granules sliding in the direction of their short edge is higher than that of the granules sliding in the direction of their long edge, which applies to rectangle-shape granules (Fig.4(b)) and half-circle-shape granules (Fig.4(a)). Therefore, it can be concluded that granular sliding direction does have effects on electrostatics. The working mechanism might be due to the sliding velocity. The relationship between sliding direction and sliding velocity is shown in Fig.4(c)(d). For both half-circle (Fig.4(c)) and rectangle granules (Fig.4(d)), their short edge as the front-facing edge slides faster than the long edge as the front-facing edge. The resistance on granules sliding in the direction of short edge is smaller than that of granules sliding in the direction of their long edge. As a result, granules gain higher velocity and more momentum and generate more electrostatics.

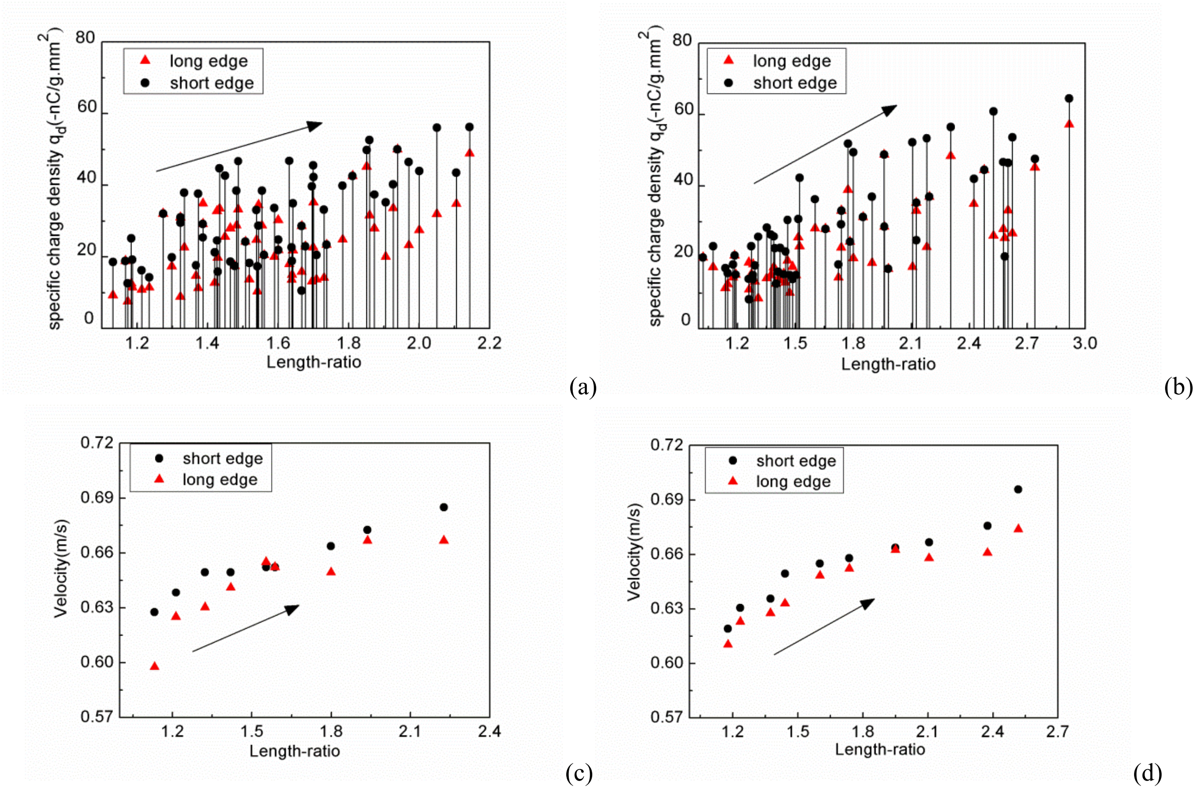


Fig.4. Front-facing edge effect on (a)-(b): charge generation: (a) half-circle; (b) rectangle; (c)-(d) sliding velocity: (c) Half-circle; (d) rectangle

3.6 Influence of plate angle

At three plate angle (30°,54°,70°), the electrostatic charge of rectangle-shape granules was tested and the result was shown Fig.5(a). our findings show that granules slide along the 54°located plate have the highest specific charge density, which indicates the highest electrostatic charges. The value of electrostatic charge generated at 30°inclined plate and 70°inclined plate has no significant difference。We observed that the granules sliding velocity of 30°inclined plate is much lower than that of 54°inclined plate. The effect of impact angle on the triboelectric charging was also investigated by Ema[24], who used an inclined target too and observed that the electrostatic charge increased with the impact angle up to 60° and then decreased. The findings are in good agreement. The friction between granules and 70°inclined plate is insufficient due to the steep plate, though the granules sliding velocity of 70°inclined plate is highest. This is a good explanation of the measured results.

Fig.5(b) presents the charging line of the four typical granules. It shows the following features: the granules basically receives negative charge by sliding along the stainless steel plane, and the amount of impact charge decreases as the initial charge approaches a certain limiting value. The limiting value is an equilibrium value. This indicates that the initial charge has effect on the electrostatics generation. Furthermore, it is found that the amount of the impact charge increases with length-ratio.

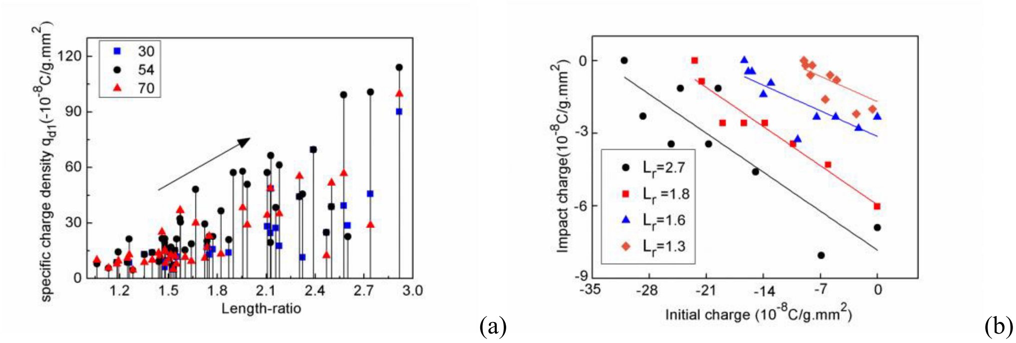


Fig.5. (a) Plate angle effect on charge generation; (b) The charging line for impacting granules

3.7 Influence of relative humidity

The sample power was placed with the earth under specified relative humidity for 24h The bar of the average charge versus relative humidity is presented in Fig.6. Each bar represents the overall average charge of granules within one range length-ratio at the certain temperature and specified relative humidity. The analysis of the results yields three observations: there is a general decrease in the amount of specific charge density(net charge transferred) as relative humidity increases, and when the air moisture content exceeds a cutoff relative humidity of 85%, the transferred charge could be neutralized. So the critical relative humidity of PVC granules is 85%. At lower relative humidity, the charge variation has a remarked tendency to increase with length-ratio. In other words, high relative humidity has a dampening effect on electrostatic charge generation. This result agreed with the experimental findings by Yao and Wang [14], who studied electrostatics of the granular flow in a pneumatic conveying system and found that particle charge densities were lower at high humidity levels and vice versa. Several mechanisms can explain the influence of the humidity on the electrostatics charge of granules. Saleh [13] favored the explanation that the adsorbed moisture on the surface of granules increased the conductivity of surfaces in contact and intensifies the charge relaxation phenomenon. W.D.Greason [25] given an interpretation that due to increased leakage caused by a decrease in the effective resistance to ground.

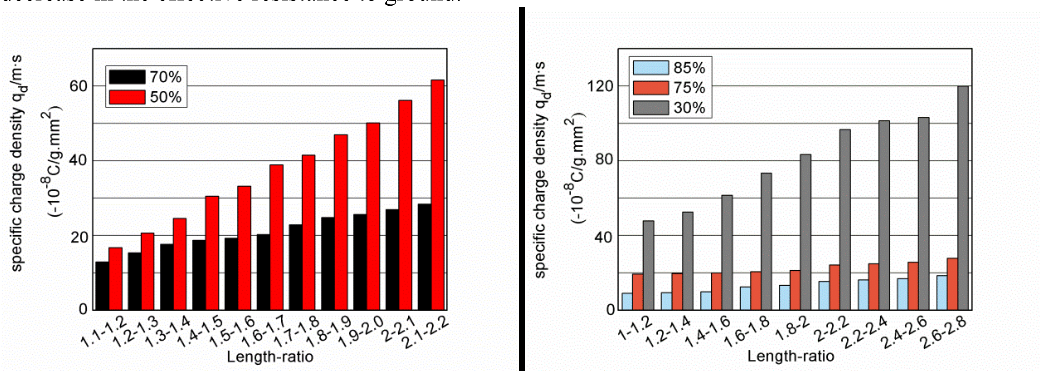


Fig.6. Relative humidity effect on average specific charge density (a) Half-circle； (b) rectangle

4 Conclusions

Sliding charging tests with single polymer granule provided one important parameters: impact charge. The impact charge is found to be proportional to the length-ratio of sliding surface and sliding area. As for the effects of front-facing edge and sliding velocity, the amount of impact charge was found to be higher in the sliding direction of short edge, due to the sliding velocity is higher when sliding in the short edge, which means that the degree of electrification increase with sliding velocity. Furthermore, the electrification level increases with the decrease in the relative humidity.

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